Comparative Study of Anterior Transvertebral Foraminotomy and Anterior Cervical Discectomy and Fusion for Unilateral Cervical Spondylotic Radiculopathy

Sho Akahori[1], Yusuke Nishimura[1], Kaoru Eguchi[1], Yoshitaka Nagashima[1], Ryo Ando[1], Takayuki Awaya[1], Takafumi Tanei[1], Masahito Hara[2], Tokumi Kanemura[3], Masakazu Takayasu[1], Ryuta Saito[1]

■ OBJECTIVE: **To study the compared surgical and radiographic outcomes of Transvertebral foraminotomy (TVF) with anterior cervical discectomy and fusion (ACDF) in patients with unilateral cervical spondylotic radiculopathy (CSR).**

■ METHODS: **We performed a retrospective comparative study of 72 consecutive patients with 1- or 2-level CSR treated with ACDF or TVF. 27 patients who underwent TVF (group T) and 45 patients who underwent ACDF (group A) with a minimum 2-year follow-up were enrolled. We evaluated clinical outcomes and radiological assessment. Clinical outcome included Visual analog scale (VAS) scores for axial, arm pain at preoperatively and final follow-up. VAS score for painful swallowing was also evaluated 1 week after surgery. Radiological assessment included C2-7 sagittal Cobb angle (C2-7 CA), range of motion (ROM) of C2-7 CA, the height, angle and ROM of the functional spinal unit (FSU), and tip of the spinous process of the operated segment. We also evaluated the disc height, FSU angle, and ROM of the FSU at the cranial adjacent segment.**

■ RESULTS: **Both groups had good clinical outcomes. Soft tissue swelling was significantly less prominent in group T than that for group A. VAS scores for painful swallowing is lower in group T without significant difference. The ROM of C2-7 CA, FSU, and spinous processes demonstrated a significant reduction in group A compared with group T.($P < 0.05$). Disc height at the cranial adjacent segment was maintained in group T.**

■ CONCLUSIONS: **TVF is as effective as ACDF for unilateral CSR and preserves whole cervical spine and segmental alignment.**

INTRODUCTION

Cervical spondylotic radiculopathy (CSR), caused by nerve root impingement, may result from cervical disc herniation and/or osteophyte formation. Anterior cervical discectomy and fusion (ACDF), first described by Smith and Robinson in 1958, is the usual treatment of choice for CSR with a high success rate.[1-5] Despite the favorable clinical outcomes of ACDF, the major drawbacks of this procedure are the loss of motion at the index level leading to adjacent segment diseases (ASD), secondary radiculopathy or myelopathy, as well as pseudarthrosis.[1,6] Charles showed that ASD and symptomatic pseudarthrosis occur more frequently as ACDF levels increase[7] with an average incidence of 12.0% and 11.1%, respectively[8,9] Anterior cervical foraminotomy, an alternative surgical procedure with preservation of the motion segment, allows surgeons to circumvent fusion-related complications with much lower

Key words
- Anterior cervical discectomy and fusion
- Transvertebral foraminotomy
- Unilateral cervical spondylotic radiculopathy

Abbreviations and Acronyms
ACDF: Anterior cervical discectomy and fusion
ASD: Adjacent segment diseases
C2-7 CA: C2-7 sagittal cobb angle
CSR: Cervical spondylotic radiculopathy
C-TDR: Cervical total disc replacement
DH: Disc height
FSU: Functional spinal unit
LCM: longus colli muscle
ROM: Range of motion
TUF: Transuncal foraminotomy
TVF: Transvertebral foraminotomy
VA: Vertebral artery
VAS: Visual analog scale

From the [1]Department of Neurosurgery, Nagoya University Graduate School of Medicine, Nagoya, Aichi; [2]Department of Neurosurgery, Aichi Medical University Graduate School of Medicine, Nagakute, Aichi; and [3]Department of Orthopedic surgery, Spine Center, Konan Kosei Hospital, Konan, Aichi, Japan

To whom correspondence should be addressed: Yusuke Nishimura, M.D., Ph.D. [E-mail: yusuken0411@med.nagoya-u.ac.jp]

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medical costs.[1,6,10] Anterior cervical foraminotomy has been developed by several surgeons since transuncal foraminotomy (TUF), which involves exposure of the vertebral artery (VA) and resection of the uncovertebral joint, was first described by Jho et al.[11] Although some authors have reported on TUF via an anterolateral approach,[12-14] these procedures have potential risks of VA injury and spinal instability by resection of the uncovertebral joint.[15,16] We have described a variant of the "minimally invasive" technique using transvertebral foraminotomy (TVF) for CSR,[17] which was a modified technique that was first developed by Yamada et al. in 1996.[18] This surgical procedure allows unilateral nerve root decompression with the intervertebral disc preserved without damaging the VA nor uncovertebral joint.

Both ACDF and TVF are indicated for CSR. However, there have been no reports comparing the clinical and radiographic results of TVF and those of ACDF. In this study, we investigated the surgical and radiographic outcomes of TVF and ACDF in patients with unilateral CSR.

MATERIALS AND METHODS

Patient Population

We performed a retrospective study of 72 consecutive patients with 1- or 2-level CSR. All patients were treated with TVF or ACDF at 2 institutions (Nagoya University Hospital and Sakura General Hospital) between October 2012 and October 2018. The study group consisted of 45 males and 27 females, with a minimum 2-year follow-up (range, 24–48 months). All patients were preoperatively diagnosed with 1- or 2-level CSR. They presented with neurological symptoms of unilateral neck or shoulder pain shooting down to the unilateral hands or fingers, corresponding to magnetic resonance imaging, computed tomography scans, and upright radiographs. All of them required surgical intervention for CSR that was refractory to conservative treatment for more than 3 months. The patients were divided into 2 groups: group T (27 patients who underwent TVF) and group A (45 patients who underwent ACDF). These groups were compared in terms of clinical and radiographic outcomes and surgical complications at the last follow-up. Unilateral foraminal stenosis with minimum or no spinal cord compression was treated via TVF, whereas unilateral foraminal stenosis with clear spinal cord compression was assigned to ACDF. The exclusion criteria were as follows: cervical myelopathy, developmental spinal canal stenosis, ossification of the posterior longitudinal ligament, spine trauma, spinal tumor, concomitant posterior fusion surgery, previous surgery at the same level, and stenosis as a result of postoperative ASD. The study was approved by the Institutional Review Board of Nagoya University and Sakura General Hospital.

Surgical Technique

Anterior Cervical Discectomy and Fusion. The patients were positioned supine on a flatbed and underwent general endotracheal intubation. Intraoperative neuromonitoring was performed in all the cases. A folded sheet was placed under the shoulders to provide a gentle neck extension. A standard Smith-Robinson approach was used to obtain access to the ventral aspect of the spine. A standard cervical discectomy was then performed followed by removing herniated discs or osteophytes compressing the PLL at the dorsal aspect of the vertebral body. The PLL was removed using a Kerrison rongeur. After ensuring complete nerve root decompression, meticulous hemostasis was achieved by using a hemostatic matrix and cotton patties. CeSpace XP titanium-coated polyetheretherketone cages (B Braun Aesculap, Tuttlingen, Germany) filled with porous hydroxyapatite/collagen composite (Refit; HOYA Technosurgical, Tokyo, Japan) were inserted into the intervertebral disc space. The wound was irrigated and closed in the usual fashion with absorbable sutures and a surgical drain.

Transvertebral Foraminotomy. The positioning of the patients and preparation were the same as those for ACDF. The spine was approached from the symptomatic side using the standard anterior method. The keyhole was placed at the middle of the height and lateral to the medial border of the longus colli muscle (LCM) attachment of the cranial vertebral body of the index level. The LCM only on the approach side was detached. The tunnel trajectory created by drilling is aimed at the lateral and caudal corners of the vertebral body. The tunnel was approximately 6 mm in diameter at the anterior cortical surface and was gradually expanded to approximately 10 mm at the end (**Figure 1**). The lateral wall of the uncovertebral joint and the integrity of the index disc space were preserved (**Figure 1**). The herniated disc fragments and osteophytes were resected through a tunnel. The deep layer of the posterior longitudinal ligament was carefully removed, and the nerve root was identified and confirmed to be decompressed. The wound was irrigated and closed in the usual fashion with absorbable sutures and a surgical drain. C4/5 level cases are not included in this group because of the difficulty in securing rostral-caudal surgical trajectory blocked by a patient's jaw.

Clinical Outcomes

Perioperative complications were investigated separately as intraoperative, early postoperative, or late postoperative complications. Early complications were assessed within 7 days postoperatively and late complications were evaluated at the final follow-up. Surgical time was recorded for both procedures. Visual analog scale (VAS) scores for axial (neck and shoulder) pain and arm pain were also, respectively, recorded preoperatively and at the final follow-up. The VAS score for painful swallowing was also assessed 1 week after surgery to assess the invasiveness of the procedures.

Radiological Assessment

Static and dynamic upright radiographs were obtained preoperatively, on the day after surgery, every 3 months in the outpatient clinic until 1 year after surgery, and every 6 months after that. Computed tomography scans were obtained preoperatively and on the day after surgery. Magnetic resonance imaging was performed preoperatively, 1 week after surgery, and 1 year post-operatively. The C2-7 sagittal Cobb angle (C2-7 CA) and range of motion (ROM) of C2-7 CA were measured (**Figure 1**). ROM was calculated as the difference in Cobb angles between full extension and flexion on the lateral radiographs. The height, angle, and ROM of the functional spinal unit (FSU; consists of 2 adjacent vertebrae and the affected intervertebral disc) of the operated

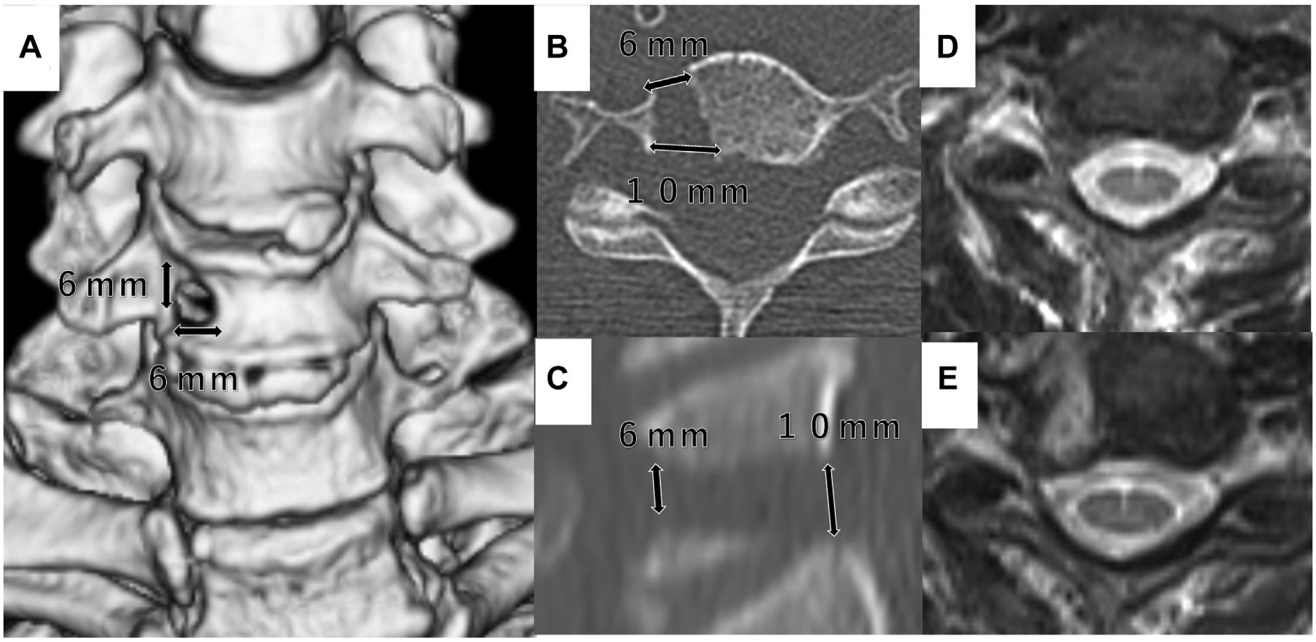

Figure 1. This case was a 67-year-old male patient with right arm pain with C7 nerve root symptoms. (**A**): The tunnel was approximately 6 mm in diameter at the cortical surface and was gradually increased to approximately 10 mm at the end. (**B**), (**C**): The medial wall of the transverse foramen and integrity of the index disc space were preserved. (**D**). Preoperative MRI shows a herniated disc compressing the intervertebral foramen. **E**; Postoperative MRI shows herniated disc removed and intervertebral foramen decompressed. The patient's symptoms had disappeared since the surgery. MRI, magnetic resonance imaging.

segment were measured (Figure 1). The ROM of the tip of the spinous process was calculated as the distance between the tip of the spinous process at full extension and flexion on lateral radiographs (Figure 2). The thickness of the prevertebral soft tissue swelling was measured on the radiographs obtained the day after surgery to evaluate the invasiveness of the procedures (Figure 2). Furthermore, cranial adjacent segment degeneration was analyzed. Only the cranial side was measured because degeneration of adjacent vertebral intervertebral segments is more common on the cranial side and because some cases at C7/T1 performed by TVF were included in this case group.[19] The disc height (DH), FSU angle, and ROM of the FSU at the cranial adjacent segment were measured preoperatively and postoperatively in each group.

Statistical Analysis

All data were presented as mean ± standard deviation . A paired *t*-test was performed to compare preoperative and postoperative radiological parameters in each group. Radiological data and VAS scores were analyzed and compared between the 2 groups using an unpaired *t*-test and a Mann-Whitney U test, respectively. Statistical significance was set at $P \leq 0.05$. The χ^2test was used to determine differences in sex and pathologies of foraminal stenosis. Statistical significance was set at $P < 0.05$. All statistical analyses were performed using SPSS (version 26.0; IBM Corporation, Armonk, NY, USA).

RESULTS

Patient Baseline Demographics

Patient demographics are shown in Table 1. This study included 72 patients with an average age of 53.5 years (range 33–76 years old). Among them, 45 patients with a total of 65 operated levels underwent ACDF (group A) and 27 patients with a total of 36 operated levels received TVF (group T). The number of operated levels per person was 1.4 ± 0.5 in Group A and 1.3 ± 0.5 in Group T, with no significant difference. The pathologies of foraminal stenosis, such as osteophytes or herniated discs, were not significantly different between the 2 groups. Likewise, sex, BMI, and follow-up duration were not significantly different between the 2 groups.

Preoperative Clinical and Radiological Parameters

The preoperative baseline VAS scores and radiological outcomes are shown in Table 2. The VAS scores for axial or arm pain, C2-7 CA, ROM of C2-7 CA, FSU height, FSU angle, ROM of FSU, and ROM of the spinous process were not significantly different between the 2 groups preoperatively.

Surgical Outcomes

Surgical outcomes are shown in Table 3. There was no significant difference in surgical time between the 2 groups. Early surgical complications included hoarseness (2 cases in group A, 1 case

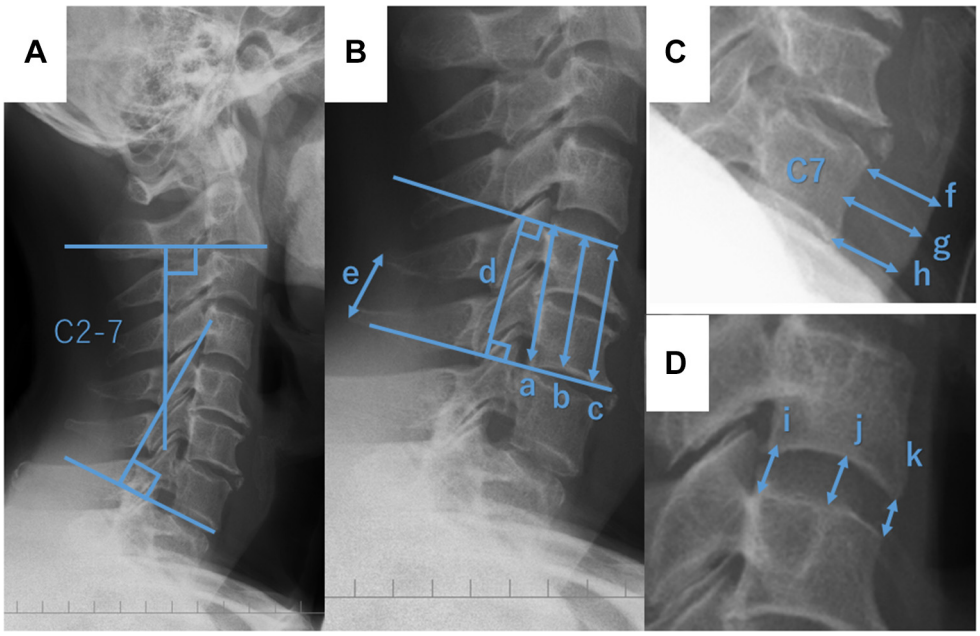

Figure 2. (**A**): On the C-spine lateral x-ray, the C2-7 CA was measured as the angle between the lower edge of the C2 vertebral body and the lower edge of the C7 endplate. The ROM of C2-7 CA was calculated by the difference in C2-7 CA between full extension and flexion in lateral radiographs. (**B**): FSU. The FSU consists of 2 vertebrae and an intervertebral disc. The FSU height was measured as the average of the 3 area heights of the 2 vertebrae (a + b + c/3). The FSU angle was measured as the angle between the upper edge of the upper vertebral body and the lower edge of the lower vertebral body (d). The FSU angle was calculated as the difference in the FSU angle between full extension and flexion on lateral radiographs. The ROM of the tip of the spinous process was calculated as the distance between the tip of the spinous process at full extension and flexion on lateral radiographs (e). (**C**): The thickness of the prevertebral soft tissue swelling was measured as the average of the 3 area widths in front of the C7 vertebrae (f + g + h/3). (**D**): The disc heights was evaluated as the average of the 3 area heights of the disc space (i + j + k/3). C2-7 CA, C2-7 sagittal Cobb angle; ROM, range of motion; FSU, Functional Spinal Unit.

in group T) and Horner syndrome (1 case in group A). All 3 cases of hoarseness were completely resolved within 1 month postoperatively. Horner syndrome completely recovered within 3 months postoperatively. Delayed surgical complications at the final follow-up include 3 cases of symptomatic recurrence at the operated level (1 case in group A and 2 cases in group T, respectively) and 1 case of cranial ASD in group A. One recurrent case at the index level in group A required posterior instrumented fusion, and 2 recurrent cases in group T were treated conservatively. The case of ASD in group A received additional ACDF. All of these 4 cases were successfully managed.

Table 1. Patient Demographics

	Group A	Group T	*P* Value
Number of patients	45	27	NA
Total number of operated levels	65	36	NA
Number of operated levels per capita	1.4 ± 0.5	1.3 ± 0.5	n.s
Age (years)	55.9 ± 11.6	50.0 ± 11.3	n.s.
Gender (Male: Female)	23: 22	20: 7	n.s.
BMI	22.7 ± 3.5	23.9 ± 3.7	n.s.
Pathology (levels) (Osteophyte: Herniated disc)	32: 33	12: 24	n.s.
Follow-up (months)	34 ± 10	36 ± 10	n.s.

NA, not applicable; n.s., not significant; BMI, body mass index.

Comparison of Preoperative and Postoperative Parameters in Each Group

Comparisons between preoperative and postoperative VAS scores and radiological outcomes of the cervical spine in each group are shown in Table 4. The preoperative VAS scores for axial or arm pain (VAS axial pain: 5.6 ± 3.5 and VAS arm pain: 7.3 ± 2.7, respectively) in group A significantly improved postoperatively (VAS axial pain: 0.8 ± 1.3, VAS arm pain: 0.8 ± 1.8, respectively). Likewise, the preoperative VAS scores for axial or arm pain (VAS axial pain: 4.7 ± 3.5, VAS arm pain: 8.0 ± 2.9, respectively) in group T also improved significantly postoperatively (VAS axial pain: 0.4 ± 0.5, VAS arm pain: 0.8 ± 0.8, respectively). The C2-7 CA and FSU angles were

Table 2. Preoperative Clinical and Radiological Parameters in Both Groups

Preoperative Score	Group A	Group T	*P* Value
VAS axial pain	5.6 ± 3.5	4.7 ± 3.5	n.s.
VAS arm pain	7.3 ± 2.7	8.0 ± 2.9	n.s.
C2-7 CA	2.2 ± 11.9	7.4 ± 11.0	n.s.
ROM of C2-7 CA	40.6 ± 12.2	37.7 ± 18.1	n.s.
FSU height	34.9 ± 3.4	36.0 ± 2.5	n.s.
FSU angle	1.0 ± 4.9	1.3 ± 3.7	n.s.
ROM of FSU	7.1 ± 3.9	7.3 ± 4.6	n.s.
ROM of spinous process	5.4 ± 3.3	5.2 ± 3.4	n.s.

VAS, visual analog scale; C2-7 CA, C2-7 sagittal Cobb angle; ROM, range of motion; FSU, Functional Spinal Unit.

significantly changed to lordotic angles postoperatively in group A, while these parameters showed no significant differences postoperatively in group T. FSU height was significantly restored in group A, while a significant reduction in FSU height was observed in group T. There were expectedly significant reductions in the ROM of C2-7 CA, FSU, and spinous process postoperatively in group A. ROM of C2-7 CA was significantly increased in group T and ROM of FSU and spinous process was successfully maintained in group T.

Comparison of Postoperative Parameters Between 2 Groups

Postoperative VAS scores and radiological outcomes were compared between the 2 groups (Table 5). Postoperative VAS scores for axial and arm pain showed no significant difference between the 2 groups. C2-7 CA, FSU height, and FSU angle showed no significant differences postoperatively between the 2 groups. The ROM of C2-7 CA, FSU, and spinous processes demonstrated a significant reduction in group A compared with group T. Soft tissue swelling on lateral radiographs on the day after surgery and VAS of painful swallowing were measured to evaluate the invasiveness of both these procedures. Soft tissue swelling was significantly less prominent in group T than in group A and VAS scores for painful swallowing tended to be lower in group T, although not significant.

Table 3. Surgical Outcomes

	Group A	Group T	*P* Value
Surgical time (minutes)	139 ± 31	134 ± 22	n.s.
Early surgical complications (number of cases)			
Hoarseness	2	1	
Horner syndrome	1	0	
Delayed surgical complications (number of cases)			
Recurrence of operated level	1	2	
Recurrence of adjacent level	1	0	

Analysis of Cranial Adjacent Segment Degeneration

The alignment of the cranial adjacent segments was assessed, as shown in Table 6. DH and FSU angle, ROM of FSU at the cranial adjacent segments were measured to evaluate cranial adjacent segment degeneration. DH was significantly reduced in group A, while DH in group T was successfully maintained. FSU angle and ROM of FSU demonstrated no significant changes in both groups.

DISCUSSION

The present study showed that TVF was as effective as ACDF for unilateral CSR. The ROM and alignment of the whole cervical spine and operated segment were nicely preserved. Furthermore, TVF appeared to be a less invasive procedure for cervical soft tissues, considering the lower VAS of painful swallowing and significantly less prominent soft tissue swelling than ACDF. ACDF can be universally applied to any type of CSR. On the other hand, surgical indications for TVF may be limited to intraforaminal stenosis because removal of hernitvated discs or osteophytes causing wide range of spinal cord compression via TVF would require excessive removal of a vertebral body and increase the risk of disc space violation, possibly resulting in spinal instability. Therefore, the surgical indications of these 2 procedures are not equal and CSR with clear spinal cord compression was operated via ACDF. From this perspective, TVF can be effectively and safely applied to CSR with intraforaminal stenosis and overtake ACDF in this group.

There are 2 main methods of anterior foraminotomy without fixation, such as TVF used in the present study and TUF. TUF has potential risks of VA injuries and spinal instability because the procedure entails total removal of the uncovertebral joints providing stability and mobility of the cervical spine in close proximity to the VA.[15,16] On the other hand, our technique of TVF creates a bone tunnel, being more medial than that of TUF, for nerve root decompression in the lateral portion of the vertebral body without removal of the uncovertebral joint. The disc space is preserved all the way through the trajectory. As a result, TVF only requires a minimum amount of violation of disc space at the back of the vertebral body when removing the herniated disc. Furthermore, the surgical indication for TVF in the present study included only intraforaminal small osteophytes or herniated discs, excluding large herniated discs projecting into the spinal canal. The intraforaminal small lesion can be removed with minimum disc space violation in contrast with large herniated discs projecting into the spinal canal. Thus, the spinal instability and VA injuries were unlikely to occur in TVF indicated for intraforaminal stenosis. We also previously proved good spinal alignment and mechanical vertebral body stability after TVF using the finite element method.[17] However, in the present study, 2 cases experienced symptomatic recurrence at the index level in TVF. TVF cases should be carefully followed up because degenerations of residual disc may progress.

Table 4. Preoperative and Postoperative Clinical and Radiological Parameters in Each Group

	Group A			Group T		
	Preoperative	Postoperative	*P* Value	Preoperative	Postoperative	*P* Value
VAS axial pain	5.6 ± 3.5	0.8 ± 1.3	$P < 0.05$	4.7 ± 3.5	0.4 ± 0.5	$P < 0.05$
VAS arm pain	7.3 ± 2.7	0.8 ± 1.8	$P < 0.05$	8.0 ± 2.9	0.8 ± 0.8	$P < 0.05$
C2-7 CA	2.2 ± 11.9	5.3 ± 13.3	$P < 0.05$	7.4 ± 11.0	9.3 ± 12.7	n.s.
ROM of C2-7 CA	40.6 ± 12.2	36.8 ± 10.6	$P < 0.05$	37.7 ± 18.1	45.0 ± 9.8	$P < 0.05$
FSU height	34.9 ± 3.4	35.7 ± 3.5	$P < 0.05$	36.0 ± 2.5	35.2 ± 2.6	$P < 0.05$
FSU angle	1.0 ± 4.9	2.0 ± 4.3	$P < 0.05$.	1.3 ± 3.7	1.4 ± 4.0	n.s.
ROM of FSU	7.1 ± 3.9	0.8 ± 2.1	$P < 0.05$	7.3 ± 4.6	6.3 ± 3.1	n.s.
ROM of spinous process	5.4 ± 3.3	1.5 ± 2.1	$P < 0.05$	5.2 ± 3.4	4.7 ± 2.8	n.s.

VAS, visual analog scale; C2-7 CA, C2-7 sagittal Cobb angle; ROM, range of motion; FSU, Functional Spinal Unit.

To the best of our knowledge, only 1 study has compared anterior foraminotomy, ACDF, and posterior foraminotomy for CSR.[20] They concluded that there was no significant difference in the effectiveness of each procedure, and ACDF was more likely to cause ASD than the other 2 procedures. ASD is the most difficult and widely recognized complication of ACDF. Carrier et al. reported that asymptomatic and symptomatic ASD occurred in 43% and 11.9% of ACDF cases, respectively during more than 2-year follow-up.[8] The frequency of symptomatic ASD in 1-level ACDF was 12.2%, which increased to 25% following 2-level ACDF during approximately 8-year follow-up.[21] As to TVF or TUF, several studies reported that the DH, FSU height, or ROM of FSU at the operated level decreased, especially 1 year postoperatively.[6,10,17,22] The present study showed that TVF could preserve the angle and ROM of FSU at the operated level while FSU height was lowered in accordance with past reports. The maintained segmental angle and ROM in group T could successfully reduce the load on the adjacent disc levels compared with ACDF. The ROM of C2-7 CA was significantly increased in group T. We attribute this to the fact that the patients in group T regained their original ROM by pain relief. As a result, the alignment of cranial adjacent segments including DH, FSU angle, and ROM of FSU was well preserved in group T. Park et al. reported additional surgeries for ASD in 2 of 44 patients after TUF during an 8.8-year follow-up,[6] and Son et al. also reported that 5 of 69 patients after TUF required revision surgeries for ASD during an 11.9-year follow-up.[10] TVF may possibly overtake TUF in terms of ASD, however, longer follow-up of TVF is necessary to reach the definite conclusion.

Table 5. Postoperative Clinical and Radiological Parameters in Both Groups

	Group A	Group T	*P* Value
VAS of axial pain	0.8 ± 1.3	0.4 ± 0.5	n.s.
VAS of arm pain	0.8 ± 1.8	0.8 ± 0.8	n.s.
C2-7 CA	5.3 ± 13.3	9.3 ± 12.7	n.s.
ROM of C2-7 CA	36.8 ± 10.6	45.0 ± 9.8	$P < 0.05$
FSU height	35.7 ± 3.5	35.2 ± 2.6	n.s.
FSU angle	2.0 ± 4.3	1.4 ± 4.0	n.s.
ROM of FSU	0.8 ± 2.1	6.3 ± 3.1	$P < 0.05$
ROM of spinous process	1.5 ± 2.1	4.7 ± 2.8	$P < 0.05$
Soft tissue swelling	5.2 ± 2.5	3.3 ± 0.5	$P < 0.05$
VAS of painful swallowing	1.9 ± 1.4	0.7 ± 1.0	n.s.

VAS, visual analog scale; C2-7 CA, C2-7 sagittal Cobb angle; ROM, range of motion; FSU, Functional Spinal Unit.

Pseudarthrosis is another possible complication of ACDF. Osteoporosis and smoking, among various other diseases, have also been reported to be closely associated with the occurrence of pseudoarthrosis.[23-25] Crawford et al. found that the probability of reoperation was 3 times (21%) higher in the pseudoarthrosis group than in the successful fusion group.[26] Yang et al. reported 7% of pseudoarthrosis rates in 2-level stand-alone ACDF with polyetheretherketone cages, while all cases of 1-level ACDF successfully fused.[27] Wang et al. showed that the rates of pseudoarthrosis increased in ACDF as more segments were operated on.[28] Based on these analyses, reducing the number of operated levels should be recommended to prevent pseudoarthrosis in ACDF. TVF can be combined with ACDF to reduce the number of fusion levels in cases of 2-or 3-level diseases by replacing ACDF.[22]

The present study demonstrated that TVF is less invasive to the soft tissues than ACDF. Soft tissue swelling was significantly less prominent in TVF, and the VAS score for swallowing pain in TVF was also lower although not significant. This less invasiveness is attributable to unilateral retraction of longs colli muscles in TVF compared with bilateral retraction of them in ACDF. Only the unilateral retraction of the LCM is sufficient in TVF, which requires only unilateral exposure of the vertebral body. Less retraction gives less soft tissue damage. We previously reported less invasiveness of TVF which requires narrower surgical exposure

Table 6. Analysis of the Parameters of Cranial Adjacent Segments

	Group A			Group T		
	Preoperative	Postoperative	*P* Value	Preoperative	Postoperative	*P* Value
DH	5.4 ± 1.0	5.2 ± 1.0	$P < 0.05$	5.4 ± 0.9	5.3 ± 0.9	n.s.
FSU angle	0.3 ± 2.4	1.0 ± 3.2	n.s.	−0.2 ± 4.3	0.6 ± 4.2	n.s.
ROM of FSU	10.6 ± 3.5	10.5 ± 3.7	n.s.	8.6 ± 4.9	8.2 ± 4.2	n.s.

DH, disc height; FSU, functional spinal unit; ROM, range of motion.

than ACDF.[29] Furthermore, Takeuchi et al. also reported more cephalad trajectory of TVF is much easier than that of ACDF at the C7/T1 level, where the usual surgical approach for ACDF can be interrupted by the sternum.[30]

Cervical total disc replacement (C-TDR) is another surgical technique that can preserve segmental mobility. A study comparing C-TDR and TVF for unilateral CSR showed equally good clinical and radiological results.[31] TVF can be an excellent surgical option for unilateral CSR with intraforaminal stenosis because it is less invasive to soft tissues and has lower medical cost even compared with C-TDR.

There are some limitations that should be noted in the present study. Firstly, this is a retrospective study with a small sample size. Secondly, cases were not randomly assigned to the 2 different surgical procedures. Cervical radiculopathy with spinal cord compression was treated with ACDF and radiculopathy cases with minimal or no spinal cord compression received TVF, thus, there exists selection bias in patient assignment. Thirdly, cases of C-TDR, a surgical technique developed with the aim of preserving motion segment and addressing the possibility of pseudoarthrosis in ACDF just like TVF, were not included in this study. A large cohort study of CSR including C-TDR cases is necessary based on our preliminary findings to pursue the evidence for the best surgical treatment for CSR.

CONCLUSION

The present study showed that TVF is as effective as ACDF for unilateral CSR with the whole cervical spine and segmental alignment preserved. Furthermore, TVF is a less invasive procedure for soft tissues, considering the lower VAS of painful swallowing and significantly reduced soft tissue swelling compared with ACDF. TVF can be an excellent surgical option for unilateral CSR caused by intraforaminal stenosis without spinal cord compression to avoid fusion-related complications with lower medical costs.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Sho Akahori: Writing — original draft, Conceptualization, Methodology, Software, Data curation. **Yusuke Nishimura:** Data curation, Writing — review & editing, Supervision. **Yoshitaka Nagashima:** Supervision. **Takayuki Awaya:** Supervision. **Takafumi Tanei:** Supervision. **Masahito Hara:** Supervision. **Tokumi Kanemura:** Supervision. **Masakazu Takayasu:** Supervision. **Ryuta Saito:** Supervision.

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